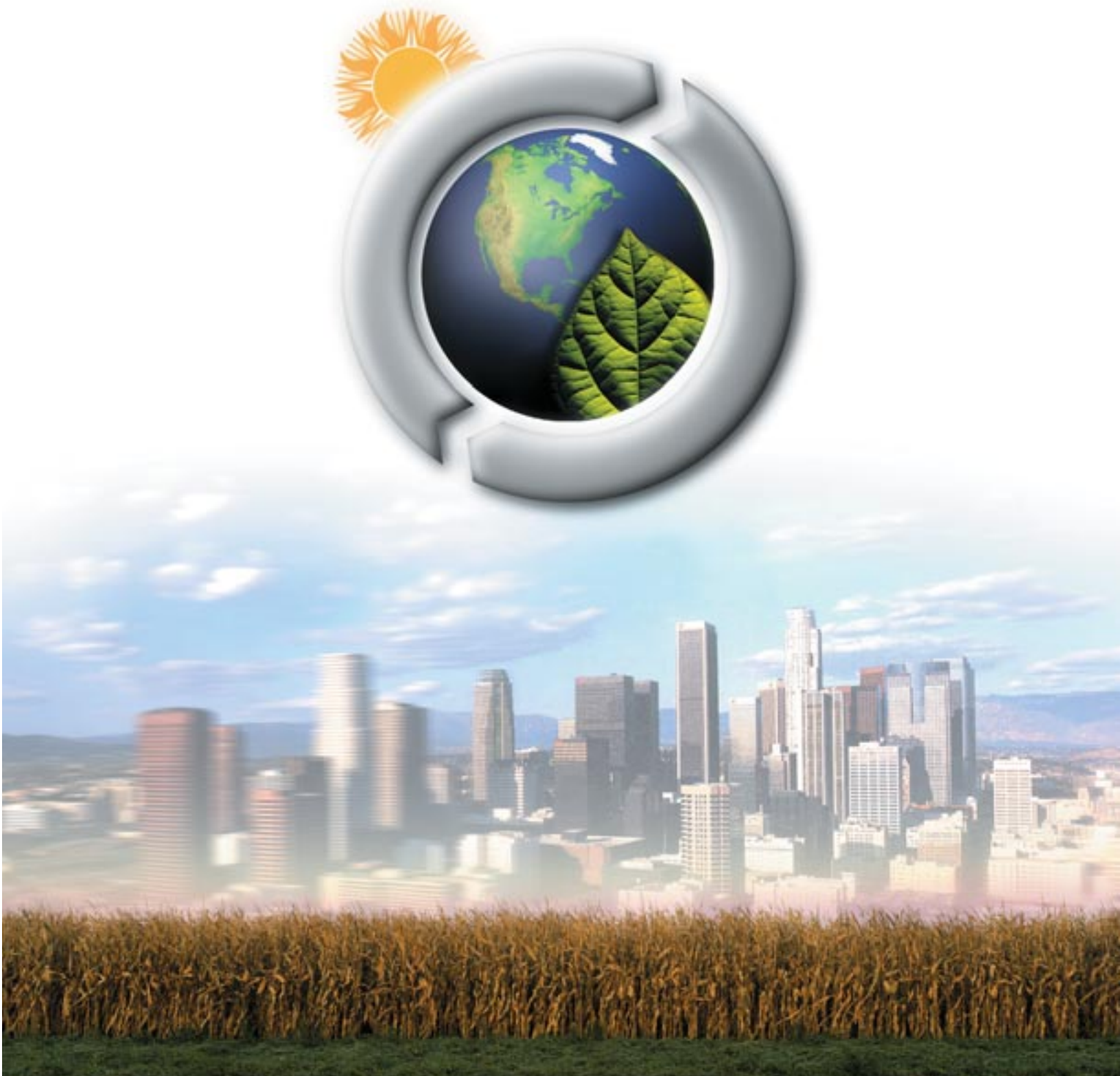
DRAFT 7/18/01

The Biobased Products and Bioenergy Vision

Achieving integrated development and use of our nation's biologically derived renewable resources



On the cover

Capturing the sun's energy

Sunlight bathes the earth every day with about 15,000 quads of energy, thousands of times more energy than human populations require.

Through photosynthesis, all green organisms have a natural mechanism for capturing some of this solar energy. This process is all around us, absorbing light energy, releasing oxygen, fixing carbon, and storing the captured energy in various chemical constituents — especially in the form of carbohydrates. Biological organisms metabolize that energy to form the familiar compounds of food, feed, fiber, and structural materials — and, over millions of years of geological time, fossil fuels like oil, natural gas, and coal. Photosynthetic energy is captured not only by land-based plants, crops, and forests, but also by pigment-containing microorganisms in lakes and oceans, where a huge amount of biomass is created. As recently as 1900, biomass provided about half of global energy supplies.

Unless otherwise noted, all projections cited in the Biobased Products and Bioenergy Vision *are from the most current reports of the Energy Information Administration of the U.S. Department of Energy. The projections generally express energy demand and consumption in quads.*

DRAFT 7/18/01

About This Vision

How powerful is the human imagination in shaping the future? This document represents the result of a disciplined effort to imagine a new energy economy, explore its implications, and communicate its potential.

A wide range of private- and public-sector participants — including biomass growers as well as leaders in industry, academia, research, and government — contributed their knowledge and expertise to the *Biobased Products and Bioenergy Vision*. Their intention has been to:

- Create an inspiring, broad-scale view of the potential of an integrated biobased products and bioenergy industry in the United States.
- Pose challenging, yet achievable, "stretch" goals and milestones for its development.
- Outline the technology, policy, and market support required for the growth of an integrated industry.
- Spur the innovative thinking, vigorous debate, investment, and action necessary to realize this Vision.

The industry leaders, scientists, and others who drafted the *Biobased Products and Bioenergy Vision (see Appendix I for list of participants)* are encouraged by recent research reports, legislative developments, and policy initiatives focusing on the role of biobased products and bioenergy in our nation's future. For example:

- In August 1999, President Clinton issued an Executive Order and Memorandum, setting a goal of tripling U.S. use of biobased products and bioenergy by 2010 and directing the Secretaries of Energy and Agriculture, the Environmental Protection Agency Administrator, the Director of the National Science Foundation, and other agency heads to develop a detailed research program to be presented annually as part of the federal budget.
- In December 1999, a committee of the National Research Council published *Biobased Industrial Products*, a report that concluded that "biobased products have the potential to improve sustainability of natural resources, environmental quality, and national security while competing economically."
- In June 2000, Congress passed the Biomass Research and Development Act of 2000 (Title III of the Agricultural Risk Protection Act of 2000), creating a research initiative focused on producing fuels, power, and chemicals from a wide variety of biomass. The bill calls for the formation of an interagency Biomass Research and Development Board, and a Biomass Research and Development Technical Advisory Committee.
- In November 1997, the President's Committee of Advisors on Science and Technology issued *Federal Energy Research and Development for the Challenges of the 21st Century*, a report that outlined the significant returns and benefits of measures to both improve our nation's energy efficiency and increase our use of bioenergy.

Keen interest in biobased products and bioenergy is also being demonstrated by the private sector. U.S. companies are leading the world in the level of investments and research they are devoting to this potentially massive new industry. The drafters of this document believe that through a strong partnership of industry and government, bioenergy can be a major element of a secure, sustainable energy future for generations to come.

Contents

2 **Executive Summary**

4 **Why Biobased Products and Bioenergy?**
Our Nation's Emerging Need for New Energy and Feedstock Sources

6 **The Vision**
Enhancing Energy Security, Environmental Quality, and Rural Economies

8 **Biomass Today and Tomorrow**
Using New Technology to Maximize the Potential of Biomass

10 **The Challenges**
Addressing Technological, Market, and Policy Issues

14 **Framework for Action**
The Pivotal Role of Public-Private Partnerships

15 **Appendices**

Executive Summary

In our children's lifetimes, the world of energy will change fundamentally. Today, our nation relies on fossil fuels for 80 percent of the energy we consume. Tomorrow, our economy will be driven by a new mix of energy sources — some currently in only limited use, some in the early stages of development, and others not yet imagined.

What will these sources of energy be? In what timeframe will they begin to augment or replace existing sources? Will they be plentiful, secure, and affordable? Will they give our children a high standard of living while also protecting the natural environment? No one can answer these questions definitively. Yet decisions and investments we make today will profoundly influence the answers.

The Promise of Biobased Products and Bioenergy

Biobased products and bioenergy — from crops, trees, and agricultural, industrial, municipal, and forestry wastes — hold great promise as contributors to the future economy. Just as we rely on photosynthesis for our food, we can also harness the energy and molecular building blocks of plants to produce fuels, provide chemical feedstocks, and generate electric power.

Currently, around 100 billion tons of biomass are created worldwide each year, with an energy value five times the total global energy consumption. Yet because it is so widely dispersed and difficult to capture, most biomass is currently burned or left to biodegrade, and little is turned into useful energy or other products. In the United States, for instance, biomass sources account for only about 3 percent of our nation's total energy consumption.

The industrial leaders and scientists who developed the *Biobased Products and Bioenergy Vision* foresee a far greater role for biomass in our nation's future:

> *Biomass resources — naturally abundant throughout our nation — will be a cornerstone of a new energy economy in the United States. An integrated biobased products and bioenergy industry will produce power, fuels, and chemicals from crops, trees, and wastes, helping to grow the U.S. economy, strengthen U.S. energy security, protect the environment, reduce greenhouse gas emissions, and revitalize rural America.*

Specifically, the Vision poses three ambitious goals for the U.S.: by **2010**, to increase the use of biobased products and bioenergy by **3-fold** over 2000 levels; by **2020**, to increase their use by **10-fold** over 2000 levels; and by **2050**, to increase their use by **another 2-fold to 3-fold** over 2020 levels.

Far-Reaching Benefits

Beyond providing the plentiful energy resources required for strong economic growth, achieving the *Biobased Products and Bioenergy Vision* will have other far-reaching benefits, contributing to:

- **Enhanced national energy security.** As a domestic energy source, bioenergy can substantially reduce our nation's dependence on imported oil.
- **Improved environmental protection**. By offsetting fossil fuel use — and related emissions of nitrogen oxides, sulfur dioxides, and other pollutants — biobased products and bioenergy can mean cleaner air and water in our communities. Further, by increasing the cultivation of carbon-fixing plants, a strong biobased products and bioenergy industry will help reduce greenhouse gas emissions that contribute to global climate change. It will also provide a productive avenue for using agricultural, industrial, municipal, and forestry wastes.
- **Rural economic growth.** Growth in biobased products and bioenergy will stimulate rural development efforts in farming, forestry, and associated service industries.
- **Sustainable global development.** By leading the way in biomass utilization, the U.S. will create useful models for sustainable development for nations around the world.

A Revolutionary Leap

Incremental growth will not be enough to achieve these visionary goals. What is called for is nothing less than a revolutionary leap forward.

The Biobased Products and Bioenergy Vision poses a bold challenge to our nation, a challenge not unlike the galvanizing call, a generation ago, that spurred Americans to reach the moon. The destination this time? A future founded on secure, renewable domestic resources and protective of the natural environment.

Unlike the moon mission, which relied on the drive and investment of the federal government to fund rapid advances in enabling science and technology, the Biobased Products and Bioenergy Vision will be achieved through investments by both industry and government. It will require the combined leadership, imagination, and skills of both the private and public sectors to make the necessary transformations in technologies, policies, and marketplaces.

Scientific progress will be key. Knowledgeable participants in the field liken the present state of biology and related sciences to that of physics in the early 20th century, when a torrent of innovation was unleashed. Today, on the threshold of the era of biotechnologies, we are witnessing fast-unfolding developments in the bioengineering of plants, the synergistic production of agricultural feeds and chemical feedstocks, and the conversion of wastes and other biomass into energy. Tomorrow, altogether new plant-based materials may be produced, specifically designed to yield novel polymers or to maximize energy content. Other technologies may tap the possibilities inherent in aquatic biomass. Toward the mid-century, engineered processes might mimic natural photosynthetic processes to directly convert the sun's rays into energy-rich materials.

Biotechnologies will help provide enough food to serve a world population at mid-century that will have grown from today's 6 billion people to close to 9 billion. The advances described in this Vision could also enable the environmentally sustainable production and use of the energy, chemicals, and products on which that future world will depend.

A Call to Action

The realization of the Biobased Products and Bioenergy Vision will require ongoing communication and education efforts to maintain the support of governmental and private-sector stakeholders. It will also require vigorous action on three fronts:

- **Scientific and technological innovation** across multiple disciplines, to maximize the potential of biomass.
- Private investment in **markets and infrastructure**, to lay the foundation for a substantial new U.S. biobased products and bioenergy industry.
- Development of **supportive government policies** that accelerate technological progress and market development.

This document characterizes major challenges in each of these three areas. And it proposes a framework for private- and public-sector partnerships to address the challenges and lay the foundation for fulfilling the promise of biobased products and bioenergy.

Today, we depend heavily on fossil fuels for energy . . .
Petroleum, natural gas, and coal provide more than 99 percent of U.S. energy for transportation, 76 percent for heating, cooling, lighting, and powering our buildings, and 89 percent related to our industries. Electricity generation is 68 percent fossil-fueled.

. . . and for valuable chemicals and products
Of the 13.9 million barrels per day of liquid hydrocarbons consumed in the United States, about 2.6 million barrels are used to create chemicals and industrial building blocks.

Why Biobased Products and Bioenergy?

Our Nation's Emerging Need for New Energy and Feedstock Sources

Economic growth in the U.S. and worldwide will depend on plentiful, affordable, and reliable supplies of energy and chemical feedstocks. Currently, fossil fuels — which are finite and nonrenewable — supply 80 percent of U.S. energy and feedstocks consumption and 86 percent of worldwide consumption. Rapid escalation in world population (expected to rise from under 6 billion today to 9 billion by 2050), coupled with rising global living standards, is projected to accelerate worldwide demand for fossil fuels over the coming decades.

How long will fossil fuel be adequate to meet global demand? Although the timing of a decline in their supply (particularly petroleum and natural gas) is widely debated, few believe we can increase fossil fuel use at the rates of the past. Most experts believe that supplementing petroleum fuels and petrochemicals with other energy resources will become necessary in the United States in the first half of this century. Factors influencing the timing include both supply-side issues, such as the success of oil companies in finding and extracting new resources, and demand-side issues, such as the levels of energy efficiency improvements that will be achieved in transportation, buildings, and industries. A major study by five national laboratories, *Scenarios of U.S. Carbon Reduction: Potential Impact of Energy Technologies by 2010 and Beyond*, recently concluded that efficiency improvements could slow the growth of U.S. energy consumption significantly.

Our nation has a range of options for supplementing petroleum, natural gas, and petrochemicals. One option is to increase use of coal, a plentiful domestic resource that could be liquefied or gasified to replace petroleum products. Environmental challenges — such as controlling emissions of nitrogen oxides and sulfur dioxides, particulates, and carbon dioxide — are the most significant barriers to increased coal use. Another option is to rely more on electricity from renewable energy sources such as hydroelectric, solar, wind, and geothermal power. Hydrogen is another renewable energy source now under development, with far-reaching potential for providing emissions-free electricity, heat, and fuel.

Biomass is a particularly promising renewable energy opportunity. Not only can biomass fuel electricity generation, but it can provide liquid fuels and chemical feedstocks as well. It also fits well with hydrogen energy strategies, in which renewable resources such as biomass, wind, and solar energy may be used to extract hydrogen from water. Potential challenges to greater biomass use include the need to balance its cultivation with other demands on our land and water resources, including food production, and to ensure the long-term safety of genetic engineering of plants.

Decisions we make in the next several years about investing in these energy options will have huge implications for future generations. They will determine our nation's energy path for decades to come.

Benefits of Biobased Products and Bioenergy

Biomass holds great promise for playing a prominent role in our future, and for dramatically benefiting the economy and environment. The development of a strong U.S. bioproducts and bioenergy industry will contribute to:

Enhanced national energy security
As a domestic energy source, biomass can substantially improve our nation's energy independence and security. Today, the U.S. imports 11 barrels of oil for every 10 barrels produced domestically. This strong dependence on imported oil for petroleum fuels and chemical feedstocks has a negative economic impact on the U.S. trade balance, and also leaves our nation exposed to potential instabilities in supply. Biomass can provide a domestic alternative to imported oil.

Improved environmental protection
Combustion of fossil fuels produces gaseous emissions — including nitrogen oxides and sulfur dioxides — that degrade air and water quality. It also emits carbon dioxide, a primary greenhouse gas contributing to global climate change. Biomass is a more environmentally friendly option. By offsetting fossil fuel use — and related emissions — biomass use can mean cleaner air and water in our communities. Further, by increasing the cultivation of carbon-fixing plants, a strong biobased products and bioenergy industry will help to stabilize or reduce greenhouse gas emissions. It will also provide avenues for productive reuse of agricultural, industrial, municipal, and forestry wastes, reducing the need for landfilling and waste burning.

Rural economic growth
A strong biobased products and bioenergy industry, which will require an increase in production and processing of biomass, will create new markets for farmers and foresters, many of whom currently face economic hardship. It will also establish new processing, distribution, and service industries in rural communities. U.S. rural areas will play a central role in utilizing agricultural, forestry, and other natural resources to provide not only food, but also energy and raw materials for plastics and other valuable products.

Support for sustainable global development
By leading the way in the biobased products and bioenergy industry, the U.S. will create useful models for other nations pursuing sustainable economic growth. Maintaining our nation's strength in biotechnologies and their application will position U.S. companies to earn a healthy share of emerging global markets for renewable energy and biobased products. We have a window of opportunity to develop and introduce supplements to petroleum fuels and petrochemicals while conditions are relatively stable. Yet, if we are to fully realize the benefits of biomass and other new energy sources in the coming decades, it is urgent that we start now to invest in new research and development, and in new markets and infrastructure.

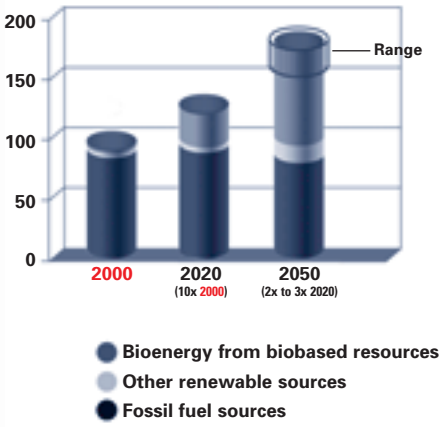
What would a 10-fold increase in biobased products and bioenergy use mean?

Achieving a 10-fold increase in biobased products and bioenergy use by 2020 would vastly increase U.S. energy self-sufficiency and reduce our reliance on fossil fuels. By 2020, the U.S. would use 30 quads of bioenergy . . .

- Equivalent to replacing virtually all U.S. crude oil imports (currently projected to range from 30 to 37 quads).
- ***Or*** enough to meet incremental demand for petroleum fuels and petrochemicals while fossil energy use is constant at today's levels.

Visionary Goals

U.S. demand for energy and feedstocks (quads)



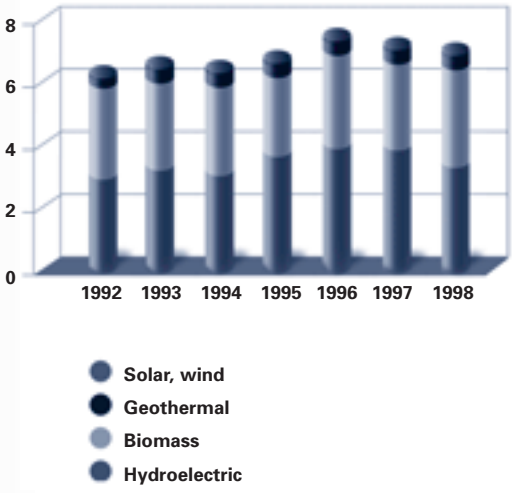
If the high-end goals of the Vision are achieved, the U.S. could rely on biomass to satisfy virtually all incremental growth in demand for energy and feedstocks through 2050.

Currently, about 8 percent of total U.S. energy use is supplied by renewables.

Hydroelectric energy is the largest source of renewable energy in the U.S. today — contributing about 9 percent of the nation's total electric power supply. While some areas of the world are developing additional hydroelectric capacity, further growth in the U.S. is limited by environmental concerns over the impact of large-scale dams. Geothermal, solar, and wind-generated power are growing and new technology and policy developments will allow increased energy from these sources.

Use of Renewable Energy in U.S.

(quads)



The Vision

Enhancing Energy Security, Environmental Quality, and Rural Economies

The Biobased Products and Bioenergy Vision foresees the emergence of a dynamic and substantial new industry in the United States that can enhance our energy security, environmental quality, and rural economies. This industry will use biomass — derived from our nation's crops, trees, and organic wastes — as a renewable source of energy and raw materials to power our businesses and homes, fuel our vehicles, and create plastics, pharmaceuticals, and other vital products.

The promise of biomass extends beyond the United States alone. Biomass has the potential to become the world's central renewable resource in this new century, contributing to global prosperity, stability, and environmental protection.

Two Assumptions Underlying Visionary Goals

A broad range of private- and public-sector participants contributed to the creation of this Vision. Participants supported "stretch" goals that would show the magnitude of the biobased products and bioenergy opportunity, stimulate innovative approaches to its development, and advance the debate on the role of biomass in our nation's future.

The visionary goals are based on a scenario in which fossil fuel use stays constant at current levels, generating a gap between future supply and demand. Meeting the targets would enable biomass to fill a major portion of that gap between now and 2020.

These targets are overall goals for biomass use as a whole, and must be reassessed over time. The actual magnitude of the contributions from biomass sources will differ among the various industries that produce and utilize energy and feedstocks. The proportion of biomass used in electricity generation, for example, will differ from that used for transportation fuels.

In establishing the visionary goals, participants made key assumptions about the future energy environment:

Assumption 1

In the face of escalating U.S. and world energy demand, both renewable and nonrenewable resources will be needed in the 20-year timeframe.

For the next several decades, fossil fuels are expected to continue to meet most of U.S. energy demand. Nevertheless, as demand for energy and consumable goods increases both in the U.S. and worldwide, renewable sources will have to be developed to supplement fossil fuels.

Predictions vary on how soon petroleum production may begin to fall short of demand, and on when — and how dramatically — its effects will be felt in our economy. In the absence of viable energy substitutes, a supply-demand gap in petroleum would be expected to cause price increases or supply shortages. Several independent sources have recently indicated that the top of the petroleum supply bell curve will be reached within 20 years.

The Biobased Products and Bioenergy Vision

Biomass resources — naturally abundant throughout our nation — will be a cornerstone of a new energy economy in the United States. An integrated biobased products and bioenergy industry will produce power, fuels, chemicals, and materials from crops, trees, and wastes, helping to grow the U.S. economy, strengthen U.S. energy security, protect the environment, reduce greenhouse gas emissions, and revitalize rural America.

Visionary Goals

By **2010**, increase the use of biobased products and bioenergy in the U.S. by **3-fold** over 2000 levels.

By **2020**, increase the use of biobased products and bioenergy in the U.S. by **10-fold** over 2000 levels.

With this significant increase, biomass would account for 25 percent of our nation's total energy consumption (including feedstocks). The U.S. would create the foundation for a secure energy future and establish its worldwide leadership in biobased products and bioenergy technologies.

By **2050**, increase the use of biobased products and bioenergy in the U.S. by **another 2-fold to 3-fold** over 2020 levels.

At this level, biomass would account for as much as 50 percent of our nation's total energy consumption (including feedstocks). The U.S. would have the capacity to be fully energy-independent, and U.S. companies would be dominant players in substantial worldwide markets for systems and services related to biobased products and bioenergy.

Assumption 2
Growth in renewables will be required in the 20-year timeframe, even though opportunities for improvements in productivity and efficiency will be broadly exploited by energy producers and by end-use sectors.

The timing of a supply-side decline in fossil fuels will be strongly determined by how well energy suppliers and users take advantage of opportunities to improve productivity and efficiency. The Biobased Products and Bioenergy Vision assumes that steady gains will be made in extracting, processing, and utilizing fossil fuels in the coming decades.

- On the energy-production side, further innovation is expected from the **petroleum industry**, which has been highly successful in using advanced exploration and production technology — like directional drilling and dimensional imaging — to extract oil and gas from increasingly remote and geologically challenging locations.
- Also on the production side, it is expected that the **electric power industry** will take advantage of such innovations as advanced turbines, fuel cells, and integrated gasification technologies in building new fossil-fueled plants to serve growing capacity demands. These new plants will be significantly more efficient than existing plants, reducing pollutant emissions per unit of electricity produced. Future progress is also expected in both pollution-control technology (e.g., nitrogen oxides reduction) and, in the longer term, in carbon-dioxide sequestration, reducing the environmental impacts of natural-gas-fired and coal-fired power generation.
- In **end-use sectors**, the Biobased Products and Bioenergy Vision assumes steady improvement in fuel efficiency in transportation, and in energy efficiency in buildings and industrial processes. A government study, *Scenarios of U.S. Carbon Reductions: Potential Impact of Energy Technologies by 2010 and Beyond* (known as the "Five Lab" study), estimates that, by 2010, improved technologies could raise energy efficiency by 10 to 15 percent in all three of these sectors (on top of projected business-as-usual savings of 10 percent), while also reducing carbon emissions. Technologies include process efficiency improvements, electrical generation improvements, and fuel switching (to biomass) for the industrial sector; energy efficiency and electricity generation for buildings; and efficiency gains and fuel switching (biofuels) for transportation. The study notes that key carbon savings come from the use of biomass systems.

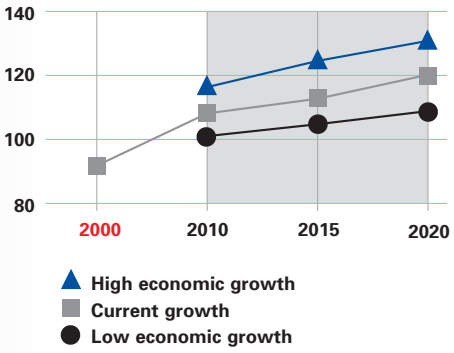
Despite improvements in energy efficiency, rapidly rising energy demand is expected to accelerate consumption of declining petroleum resources. Viable energy substitutes will become increasingly critical to national (and global) development.

Demand for energy and consumer products is expected to grow sharply.

- In the U.S., consumption of energy, power, and petrochemical-based materials is over 94 quads per year. By 2020, consumption is projected to grow by 27 percent, or an additional 25 quads.
- The world currently consumes 360 quads of energy per year. A 75 percent increase is projected by 2020, or an additional 270 quads.

A number of factors could slow this energy demand growth, including a downturn in economic growth or an increase in energy efficiency in buildings, vehicles, and industry. Nevertheless, our nation and the world will ultimately need new sources of energy to replace non-renewable sources.

Projected U.S. Energy Demand
(quads)



Projected U.S. demand for energy varies depending on the economic growth assumptions used. Another key variable is the impact of energy efficiency, which could be improved by 15 percent or more by 2010.

Biomass Today and Tomorrow

New Technology Can Maximize the Potential of Biomass

Today, biomass makes a useful but minor contribution to meeting U.S. energy and product needs. Tomorrow, our nation can benefit from using biomass as the cornerstone of a sustainable future.

A substantial leap must be made from today's modest levels of biomass utilization. Realizing the promise of the Biobased Products and Bioenergy Vision will require significant advances in science and technology to increase the availability, utilization, and cost-effectiveness of biomass. The potential for scientific advances is so great that it is useful to think in terms of an entirely new category of biomass resources and processes — "new biomass" — augmenting traditional biomass forms in the future.

New Biomass

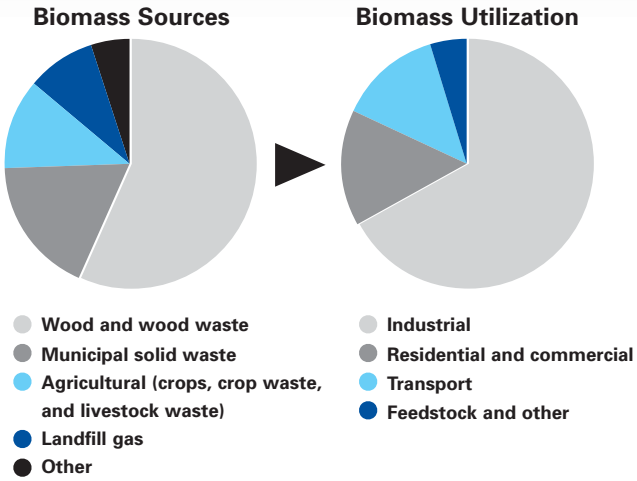
To realize the long-range Biobased Products and Bioenergy Vision, we must draw on a larger and more diverse range of biomass resources than those typically used today. Improved land use, waste utilization, and crop management, together with modified processing methods, will augment biomass utilization. In addition, new methods of cultivating and harvesting aquatic organisms may someday enable the earth's lakes and oceans to supplement forests and farms as important sources of biomass. Other avenues for creating new biomass resources are being opened by dramatic scientific developments in such areas as genomics and transgenic plants.

The use of genetic biotechnologies is a controversial issue in today's world. Already, such technologies are widely applied in agriculture, resulting in impressive gains in productivity and yields. Yet the longer-term ecological and health effects of genetic biotechnologies are the subject of debate. Solid scientific studies of these effects must be a priority, so that informed decisions about technology applications — in bioenergy as well as in agriculture and other industries — can be made.

The potential benefits of genetic biotechnologies are great. Advances in these areas could make it possible to engineer valuable new types of plant-based materials with altered constituents, including plants and microorganisms specifically designed to yield novel polymers or to maximize carbon for high-energy content. It may be feasible, for example, to fix carbon into high-energy "living oils" (oil contains 17,200 Btu per pound) rather than

Today, biomass accounts for about 3 percent of U.S. energy consumption.

Today, traditional biomass (primarily wood, wood by-products, grains, agricultural and livestock wastes, straw, landfill gases, and municipal solid wastes) from the nation's farms, forests, pulp and paper mills, and landfills makes a useful, but minor, contribution to meeting U.S. demand for fuel, electric power, and chemical feedstocks. Consumption of these biomass resources has been increasing by more than 2 percent annually since 1990 in most regions of the country.



The **industrial** sector currently makes the greatest use of biomass. Most significant is the pulp and paper industry, which uses wood to produce nearly 60 percent of its internal heat and power needs.

Residential and commercial use is largely related to wood utilization for space heating. About 3 million homes in the U.S. depend solely on wood, while around 20 million use wood heating as a supplement. Small wood-waste-fueled gasifiers are in operation at institutional facilities in the northeast U.S.

Transportation use consists almost entirely of ethanol for blending with gasoline. Approximately 95 percent of biobased ethanol is produced by fermenting 550 million bushels of corn grain. In addition, a small amount of biodiesel (methyl esters of vegetable oils) is made from soybean and other vegetable oils.

Biomass currently accounts for only about 2 percent of **feedstocks for petrochemical processes**, such as plastics and pharmaceuticals production. The petrochemical industry has evolved a sophisticated degradation and re-synthesis system that successfully provides raw materials at acceptable cost.

Finally, **utilities** use biomass to generate a small amount of electricity (about 1 percent of total U.S. electricity use) by burning biomass to drive steam turbines, cofiring biomass with coal, and using methane from landfill gas.

just combusting structural lignin (lignin contains 11,400 Btu per pound) into energy. Genetic biotechnologies can also enable farmers and foresters to increase yields and to cultivate crops specifically for biobased products and bioenergy markets while still providing plentiful food, feed, and wood products.

Recent developments in the efficient enzymatic conversion of corn carbohydrates to polylactic acid (PLA) and other polymers provide a clue to the potential of new biomass. PLA is a biodegradable polymer that has useful characteristics for the manufacture of plastics, fibers, and other everyday materials. Today, modern biotechnology has enabled a new process that can make PLA resins cost-competitive with current petrochemical-based products. The first production plant will be constructed in Nebraska, close to the source of corn inputs.

By 2020, biorefineries could draw upon diverse sources — including agricultural and forestry products, as well as methane from landfills and animal and plant wastes — to produce both useable energy and biobased substitutes for petrochemical feedstocks.

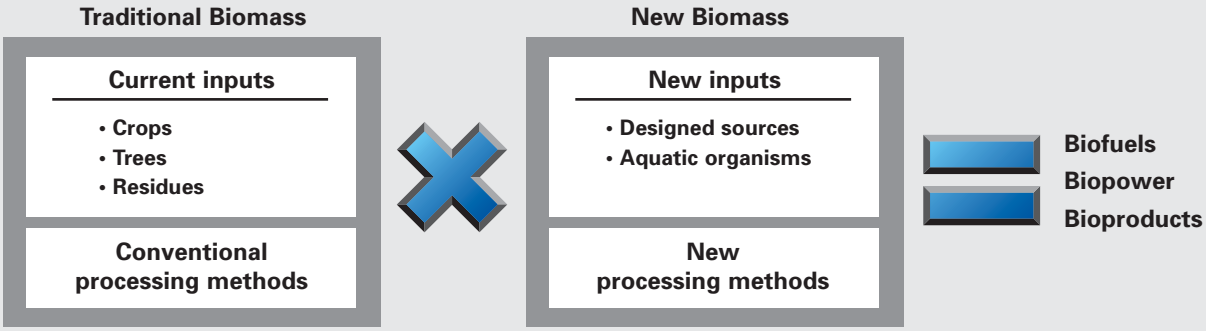
In the longer term (up to 2050), biotechnologies are likely to create even more remarkable opportunities. For example, photosynthetic processes and special enzymes may be combined to create solid structures, analogous to solar panels today, that would intercept sunlight and fix carbon into energy-rich materials. Other developments, now scarcely imaginable, will arise from the continued evolution of biomass as the renewable resource of choice.

Traditional Biomass

Continued research and development also will enable more effective capture and utilization of the energy content from traditional biomass (lignin and cellulosics). For example, processing techniques such as advanced gasification show promise for more efficient energy retrieval from biomass. In the area of biofuels, research into enzymatic conversion of lignocellulosic biomass is opening the way to the cost-effective use of agricultural crops, residues, and fast-growing trees and plant parts (like stems) to produce ethanol. Other projects are exploring the cultivation of hybrid poplar or willow, switchgrass, and other rapidly growing plants that can produce high yields of lignin and cellulose per acre per unit time. In some cases these special crops may be grown on land that is considered marginal for viable grain production. However, concerns about the potential environmental effects of using such lands must first be addressed.

By pursuing the integrated development of both traditional biomass and new biomass resources, our nation will gain a portfolio of renewable inputs for producing its energy, power, and manufacturing building blocks, and will ensure a foundation for sustainable national economic growth.

New biomass inputs and processing methods will provide the foundation for a competitive biobased products and bioenergy industry.



Traditional biomass inputs, typically high in lignin and cellulosic content, are derived primarily from crops and trees, a waste pool of forestry, crop, and process residues, and wastes from municipal and livestock operations.

In the future, biomass inputs will include plants specifically designed for energy and bioproduct applications, as well as sources such as aquatic organisms. New processes will more efficiently convert biomass into energy and basic molecular building blocks.

The Challenges

Addressing Technological, Market, and Policy Issues

The United States has all the fundamental resources needed to develop biomass as a primary renewable energy source: good soils, extensive natural water distribution, and the technology capabilities to ensure resource protection while generating a wealth of renewable biomass products.

Yet formidable challenges must be addressed before our nation can realize the full potential of biobased products and bioenergy. One set of challenges involves determining the longer-term ecological, health, and economic implications of biotechnologies. Dialogue among a wide range of stakeholders, with supporting input from peer-reviewed scientific studies, will be required to address the concerns and opportunities associated with these technologies.

Other challenges are economic. Like other emerging technologies, biobased products and bioenergy must navigate a development curve, reaching a point at which their demonstrated value makes them successful and competitive in the marketplace. Reaching this point will require focused efforts on three fronts:

Technologies
Scientific and technological innovation is needed across multiple disciplines to maximize the potential of biomass.

Markets
Substantial private investment in markets and infrastructure will be required to lay the foundation for the new U.S. biobased products and bioenergy industry.

Policies
Development of supportive government policies will accelerate both technological progress and market development, while protecting our environment.

Technology Issues

Advances in the science and technology of biobased products and bioenergy will be key to enhancing their value and cost-competitiveness in the marketplace. Tomorrow's technologies will open doors to new biomass sources, including economically viable, dedicated energy crops and trees; and to fully integrated processes for cost-effective coproduction of fuels, power, and chemicals from both new and traditional biomass sources.

No one industry alone can provide the basis for major gains in biobased products and bioenergy. Although exciting research opportunities exist in areas such as biopolymers, stereospecific molecules, new enzymes, novel materials, and transgenic design, progress in isolated technical areas will not be sufficient.

To address the complex requirements of an integrated biobased products and bioenergy industry, research must be multidisciplinary, focused, and coordinated. (For example, the study of gene regulation must be closely interrelated with the study of functionality of inherent polymers, and these with separations engineering.) An overriding requirement will be greater focus on biochemistry and bioprocesses in technical education and training.

Areas of technology development that will support biobased products and bioenergy include the following.

Plant sciences*
A major research focus will be altering plant metabolic pathways to produce certain carbon molecules with valuable functional properties and to ensure the long-term sustainability of biomass production. Among the key needs are:

- Improved understanding of inherent plant metabolism and regulation of carbon flow, enabling design of particular characteristics — such as higher oil content, more or less lignin, etc. — depending on the targeted use of the plant in bioenergy or bioproducts.
- Research on genetic transformation to allow more specific gene insertion and routine transformation of plastids as well as nuclear events.
- Scientific studies on the longer-term impacts of genetically engineered biomass on the ecosystem, enabling sound decision-making about the applications of genetic biotechnologies.

Production and collection
Major objectives will be economically viable production, harvesting, and handling, together with the lowering of unit product costs for consistent-quality raw materials. Among the research, development, and deployment needs are:

- Improved productivity in terms of yield per acre and yield per unit input.
- Efficient systems for design, production, and handling of dedicated crops.
- Study of the requirements for chemical consistency of plant-derived materials in different energy and product applications.
- Improved theory and practice of sustainable agriculture and forest management, to maintain biodiversity and support all ecosystem functions — including food and feed production, watershed stabilization, groundwater quality, habitat diversity, soil conservation, and contributions to the atmospheric carbon dioxide balance — while also increasing yields of biomass for wood products, energy, and feedstocks.
- Improved understanding of the factors (e.g., seasonal variations, weather, soil chemistry) affecting consistency in quality and quantity of biomass products, including harvest yields.
- Continued application of new biotechnologies to maintain agricultural productivity increases.

Processing and conversion
This area encompasses all aspects of separating and converting biomass materials into power, fuels, and products. Research, development, and deployment needs include:

- Economical new techniques for separating plant components.
- Further progress in processing (e.g., using thermal or enzymatic approaches) to continue lowering the costs of extracting energy and products from traditional biomass sources.
- More effective conversion processes for biomass materials (e.g., using high-performance multifunctional biocatalysts or heterogeneous catalysts that can perform multiple tasks and are recyclable, further improved gasification and combined cycle power technologies, etc.).
- Improved fermentation processes (e.g., ability to perform more types of conversions, better use of by-products, and improved separation capabilities).
- Improved reduction chemistry for plant-based systems, and development of practical co-factor systems for reductive biocatalysts.
- Further development, capital-cost reduction, and successful demonstration of existing or near-term technologies (e.g., biomass combustion and steam systems for power, ethanol production from corn and lignocellulosics, and gasification for power and fuels.)
- Improved biopower systems, including gasification and pyrolysis, gas cleanup, feedstock handling, and ash use.
- Application of advanced processing strategies in biorefineries to co-produce a mix of fuels, power, and products.

Uses and distribution
The focus here is to optimize end-use and distribution of biobased products and bioenergy in a wide variety of applications (consumer goods, power, heating and cooling, infrastructure, transportation, buildings). Research, development, and deployment needs include:

- Improved understanding of functionality (performance) relative to cost of plant-derived polymers.
- Fuel formulation, including the use of plant-derived materials or genetically altered plants to provide constituents with the desired energy content and functionality.
- Research on public perceptions and concerns about biotechnology.
- Research on new markets (including price and value assessments).
- Development of life-cycle assessment (LCA) models for evaluating environmental performance.

**While this document focuses primarily on the promise of plant-based biomass technologies, future investigations can and should be made regarding utilization of animal wastes.*

Market Issues

Throughout the past century, our nation — and the world as a whole — has invested in an enormous and sophisticated infrastructure for researching, producing, processing, securing, distributing, and utilizing fossil energy. The fossil energy infrastructure includes not only physical assets, but also intellectual assets, representing the cumulative knowledge gained through many billions of dollars in public and private research. As a sunk cost, this infrastructure favors the continued use of fossil energy and petrochemical products in cost comparisons with bioenergy and biobased products.

At some future point, when crude oil prices increase due to declining production, and when environmental results of increased use of fossil sources are factored into their costs, comparative-cost equations can be expected to favor bioenergy and biobased products. Long before this point, however, our nation will need to begin investing in bioenergy infrastructure and market development if this renewable source is to be a significant part of our energy future. By improving the value, efficiencies, and economies of scale associated with bioenergy and biobased products, this new industry will become increasingly competitive and will be positioned to deliver plentiful, affordable power, fuels, chemicals, and materials when they are needed to supplement petroleum-based products.

The U.S. can spur the development of the necessary infrastructure and markets in a number of ways. An immediate opportunity is to take full advantage of market niches where biobased products and bioenergy applications can be cost-effective today or in the very near term.

Producers of corn and soybeans are already involved in expanding use of their products for fuel and chemical feedstocks. Other promising niches include markets where biomass inputs are concentrated, making them economical to gather and process on site. The pulp and paper industry, for example, has developed successful systems to use wood waste in generating heat and electricity. A similar scenario might be realized in utilizing millions of tons of crop residues. Around 45 percent of the dry matter in American fields remains after the harvest. While a certain amount of this residue is needed to maintain good soil and prevent erosion, most of it could be collected and transported to local sites for processing.

Traditionally, the cost of collecting and transporting agricultural and animal wastes for processing into biobased products and bioenergy has been prohibitive. Broader use of agricultural and animal wastes and other residues can become economically favorable, however, where other factors, such as regulations governing waste, create incentives for biomass recycling. Collection and use of biomass can provide farmers with an attractive alternative to open-field burning and landfilling of wastes.

While these opportunities are valuable, achieving the Biobased Products and Bioenergy Vision will require market development well beyond today's niche opportunities and beyond the use of biomass residues alone. Focused economic research and development will be required to develop:

- Improved understanding of the economics of feedstock or energy crop cultivation and utilization from the perspective of the farmer or forester.
- Improved understanding of the collection, processing, and distribution infrastructure that will be necessary for large-scale biomass utilization, including analysis of the cost impact of distance between processing sites (e.g., biorefineries) and biomass concentrations.
- Improved understanding and optimization of life-cycle emissions, energy ratios, and cost for existing and new bioenergy and bioproduct systems.
- Studies of the economic feasibility of biorefinery modules in reducing costs of biomass collection and transport. These studies would include small, perhaps portable, systems.
- Models of broad-scale biobased products and bioenergy market development, identifying the impacts of different economic scenarios and the most effective drivers and incentives within each scenario.
- Models of rural development to support production, processing, and utilization of biomass, including the potential roles of farmer-owned manufacturing cooperatives.
- Models of integrated approaches for deriving optimum value from biomass (e.g., energy plants using diverse biomass feedstocks to produce multiple energy and chemical products).
- Improved understanding of possible integration between processing and distribution infrastructures for biobased products/bioenergy and petroleum/petrochemical products.

- "No waste" systems approaches to the use of processing by-products, where any unused materials in one process become the inputs for the next process and where optimum value of each material is captured across the system (as in large corn wet milling facilities).
- Standards for biobased products that will enable their substitution for petroleum and petrochemical products.

Policy Issues

Supportive federal, state, and regional government policies will be an essential foundation for realizing the promise of this Vision. Policies governing a wide range of areas — from transportation to rural development, from agriculture to commerce, from environmental protection to energy security, and from land conservation to education — will have an impact on the future of biobased products and bioenergy.

One particular concern is ensuring that our nation's arable lands are used in balanced ways, supporting our needs for agricultural and forestry production, environmental preservation, and human and wildlife habitats, as well as biomass cultivation.

Another issue that must have attention is demonstrating the safety of genetic engineering of plant and tree life. Continuing protocols must be developed to ensure that rigorous environmental investigations are part and parcel of every significant technological advance.

Policies will affect how quickly and fully different energy markets will adopt biobased products and bioenergy. For example, restructuring of the electricity industry is expected to open new opportunities for distributed generation. This trend can encourage the use of biomass as a feedstock, provided that small, distributed power generators have equitable acccess to the electricity transmission grid.

Developing an effective policy framework will require assessing current biomass-related policies at the federal, state, and regional levels, and devising policy options that expand opportunities for biomass production and use. Specifically, an effective policy framework would remove or reduce market barriers to biomass; encourage state and federal procurement of bioenergy and biobased products; and establish standards for bioproduct quality, performance, and safety. Ideally, standards and regulations affecting biobased products and bioenergy will be performance-based and will encourage innovation in products and processes.

The federal government can also play a vital role in education and outreach, providing information on the benefits of biobased products and bioenergy to states, communities, farms, industries, and consumers, and helping to stimulate market awareness. For example, the government might promote labeling of biobased products, through a federal program similar to Energy Star, to support the development of market demand.

Finally, important government contributions to the development of biobased products and bioenergy can include tax incentives of various sorts, such as incentives for capital investment in infrastructures; facilitation of technology transfer; and cost-sharing of research, development, and demonstration projects with industry.

Currently, different federal offices sponsor programs related to biobased products and bioenergy, each with an independent focus on fuels, power, or chemicals. More coordinated and collaborative research efforts across these sectors can stimulate new and innovative products and processes, and lead to the development of integrated operations (e.g., multi-product biorefineries) that will maximize the cost-competitiveness of biobased products and bioenergy. Furthermore, increased integration of biomass research, development, and deployment programs can reduce the time it takes for improved concepts to travel from the laboratory to the marketplace.

Framework for Action

The Pivotal Role of Public-Private Partnerships

The Biobased Products and Bioenergy Vision foresees the emergence of a dynamic, integrated industry by 2020 that will use plant products to satisfy a significant portion of our nation's demand for energy and chemical products, as well as for our food, feed, and wood products. As a result, the United States will gain the basis or a secure and sustainable energy future and will enhance protection of the environment.

Achieving the Biobased Products and Bioenergy Vision will take a cohesive, integrated effort across multiple disciplines, driven by a new partnership among industries, government agencies, farmers, nongovernmental organizations, and laboratories. This partnership must draw together the different sectors of today's biomass industries — power, fuels, and chemicals — and advance the technologies, policies, and market development needed to create an integrated biobased economy for the future.

The partnership will foster better collaboration and communication among biomass stakeholders in order to take advantage of inherent synergies and exploit emerging market opportunities. It will reassess the Biobased Products and Bioenergy Vision goals over time and reach agreement on the most productive pathways for achieving a shared vision of the future. It will also address the need for more effective public policies at the federal, regional, and state levels to support a robust biobased products and bioenergy industry.

Development of an integrated biobased products and bioenergy roadmap, including specific targets and timelines, is recommended to stimulate both private and public investment in support of the long-term vision. The roadmap would address:

- **Technology**, identifying high-priority research and development opportunities across the power, fuels, and chemicals sectors. The roadmap will build on the roadmapping activities already under way in the Department of Energy, and will identify ways to coordinate biomass RD&D with other renewable and fossil energy technology programs. It will also identify requirements for supporting analysis (e.g., expected performance of process-specific technologies).
- **Market development**, identifying needs and opportunities across the power, fuels, and chemicals sectors, and defining requirements for supporting analysis (e.g., studies of market potential for different approaches to the production and use of biomass resources).
- **Policy**, assessing current biomass-related policies at the federal, regional, and state levels, and outlining policy options that expand opportunities for biomass production and use. The roadmap will identify areas for supporting analysis (e.g., studies of the potential contributions of biomass use in addressing global climate change), and will define ways to increase federal-state coordination (e.g., increased interagency communication and expanded technical assistance to state and regional agricultural and forestry programs).

Ultimately, the roadmapping process and other partnership efforts will help to stimulate the sustained, long-term private and public investments required to grow a competitive biobased products and bioenergy industry.

The potential benefits of biobased products and bioenergy — in enhancing our energy security, safeguarding our environment, and providing the basis for economic growth — make these public and private investments among the most vital our nation will make in this generation, on behalf of generations to come.

Appendix 1

Participants in Biobased Products and Bioenergy Vision Development

A broad range of private- and public-sector organizations provided inputs and comments for the Biobased Products and Bioenergy Vision. In particular, the following people made important contributions in conjunction with three workshops held in St. Louis (March 1999) and Washington, D.C. (June and December 1999).

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Appendix 2

Definitions

barrel (bbl)
Equivalent to 42 U.S. gallons. The energy in one bbl is equivalent to 5.8 million Btu. One quad is about 172 million bbl.

biobased resources
Material and/or energy derived from biological origins within biological time.

bioenergy
Energy, fuel, or feedstocks derived from biomass or biobased source(s).

biofuel
A liquid fuel made from biomass via either thermal conversion (e.g. gasification) or biological conversion (e.g. enzymatic and fermentation combinations). Products such as ethanol, methanol, or methyl soyate (biodiesel) are typically used as transportation fuel additives.

biomass
Material derived from biological origins within biological time; or alternatively, any mass created through photosynthesis to fix carbon. Traditional biomass is often used to denote lignin- and cellulose-containing materials.

biopower
Electricity or a storage form of energy from biomass.

British thermal unit (Btu)
Measure of energy based on the amount of heat required to raise the temperature of one pound of water from 59°F to 60°F at one atmosphere pressure.

cofiring
Combustion of mixed materials. For example, wood chips with coal.

cogeneration
The production of electricity plus another energy type. For example, locally produced steam may drive an electricity-generating turbine and subsequently be used for heating at other locations in the facility.

combustion
The oxidative burning of material, typically under normal atmospheric pressure. Internal combustion would be under pressure as in an engine.

fossil fuels
Coal, natural gas, crude oil, etc. — derived from biological sources but in a geological timeframe.

gasification
Thermal conversion of biomass using air, oxygen, and/or steam to produce either a low or medium calorific value fuel gas or synthesis gas. The fuel gas could drive a combined-cycle turbine for power production, and the synthesis gas could be further processed to produce liquid fuels, chemicals, and/or products.

horsepower
A measure of mechanical energy output. Conversions 1 hp = 745.7 watts = 2,545 Btu/hr.

pyrolysis
The decomposition of biomass by heating at very high temperatures in the absence of oxygen. The production of char (solid), pyrolysis oil (black liquid), gas (methane, etc.) depends on the conditions of heat, pressure, oxygenation, etc.

quad
A quadrillion Btu (10^{15}, British thermal units).

renewable energy
Energy derived from a source that can be regenerated or is inexhaustible. For example, biomass, hydropower, wind, solar, or geothermal.

renewable resources
Resources derived from plant-based primary-energy-capture mechanisms in an annual or few-year timeframe, or from other regenerative sources. Could be energy, structural material, or chemicals.

watt
A basic unit of power equivalent to 3.413 Btu/hr. 1 kilowatt hour (kWh) is a measure of energy equal to using 1,000 watts for one hour.

DRAFT 7/18/01

DRAFT 7/18/01

Issued by the National Biobased Products and Bioenergy Coordination Office.

If you have questions or comments, please call (202) 586-7766.

July 2001

Printed with a renewable-source ink on recycled paper.

DOE/GO-####